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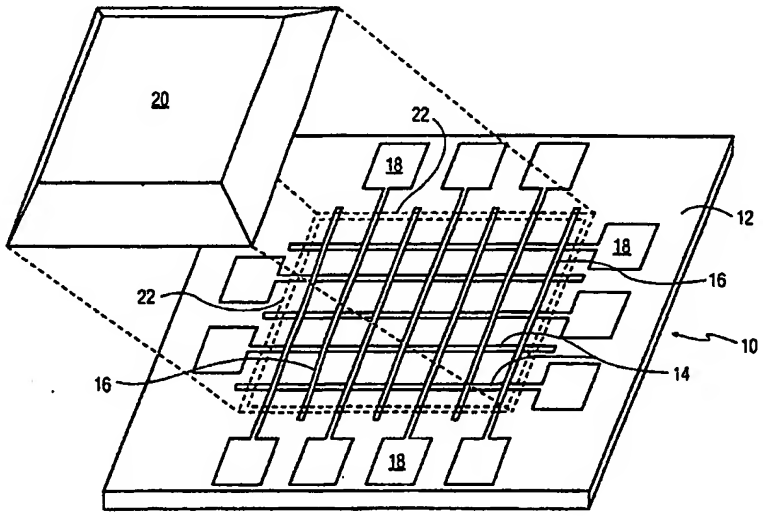

(57) Abstract

An electrophoretic display (10) is provided which enables an image to be displayed by selectively energizing intersecting grid (16) and cathode (14) lines each indicative of a pixel and varying the bias between the lines to cause suspended pigment particles to migrate to an anode (20) and away from the energized pixels. Selected intersections of grid (16) and cathode (14) lines indicative of pixels are energized with a set of voltages during a fixed time interval, thereby causing an image to be displayed thereon. The time interval selected is less than the time required to completely remove the pigment particles from the pixels and the image is sequentially enhanced by rewriting at least some of the pixels with the set of voltages at least once. This permits a readable image to be produced much more rapidly and also provides incrementally darker pixels in the image as additional pigment particles are moved from selected intersections during subsequent energizing intervals.

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"ELECTROPHORETIC DISPLAY HAVING REDUCED WRITING TIME"

BACKGROUND ART

Electrophoretic displays (EPIDS) are now well known. A variety of display types and features are taught in several patents issued in the names of the inventors herein, Frank J. DiSanto and Denis A. Krusos and assigned to the assignee herein, Copytele, Inc. of Huntington Station, New York. For example, U.S. Patent Nos. 4,655,897 and 4,732,830, each entitled **ELECTROPHORETIC DISPLAY PANELS AND ASSOCIATED METHODS** describe the basic operation and construction of an electrophoretic display. U.S. Patent No. 4,742,345, entitled **ELECTROPHORETIC DISPLAY PANELS AND METHODS THEREFOR,** describes a display having improved alignment and contrast. Many other patents regarding such displays are also assigned to Copytele, Inc.

The display panels shown in the above-mentioned patents operate upon the same basic principle, viz., if a suspension of electrically charged pigment particles in a dielectric fluid is subjected to an applied electrostatic field, the pigment particles will migrate through the fluid in response to the electrostatic field. Given a substantially homogeneous suspension of particles having a pigment color different from that of the dielectric fluid, if the applied electrostatic field is localized it will cause a visually observable localized pigment particle migration. The localized pigment particle migration results either in a localized area of concentration or rarefaction of particles depending upon the polarity and direction of the electrostatic field and the charge on the pigment particles.

The electrophoretic display apparatus taught in the foregoing U.S. Patents are "triode-type" displays having a plurality of independent, parallel, cathode row conductor elements or "lines" deposited in the horizontal on one surface of a glass viewing screen. A layer of insulating photoresist material deposited over the cathode elements and photoetched down to the cathode elements to yield a plurality of insulator strips positioned at right angles to the cathode elements, forms the substrate for a plurality of independent, parallel column or grid conductor elements or "lines" running in the vertical direction. A glass cap member forms a fluid-tight seal with the viewing window along the cap's peripheral edge for containing the fluid suspension and also acts as a substrate for an anode plate deposited on the interior flat surface of the cap. When the cap is in place, the anode surface is in spaced parallel relation to both the cathode elements and the grid elements. Given a specific particulate suspension, the sign of the electrostatic charge which will attract and repel the pigment particles will be known. The cathode element voltage, the anode voltage, and the grid element voltage can then be ascertained such that when a particular voltage is applied to the cathode and another voltage is applied to the grid, the area proximate their intersection will assume a net charge sufficient to attract or repel pigment particles in suspension in the dielectric fluid. Since numerous cathode and grid lines are employed, there are numerous discrete intersection points which can be controlled by varying the voltage on the cathode and grid elements to cause localized visible regions of pigment concentration and rarefaction. Essentially then, the operating voltages on both cathode and grid must be able to assume at least two states corresponding to a logical one and a logical zero. Logical one for the cathode may either correspond to attraction or repulsion of pigment. Typically, the cathode and grid voltages are selected such that only

when both are a logical one at a particular intersection point, will a sufficient electrostatic field be present at the intersection relative to the anode to cause the writing of a visual bit of information on the display through migration of pigment particles. The bit may be erased, e.g., upon a reversal of polarity and a logical zero-zero state occurring at the intersection coordinated with an erase voltage gradient between anode and cathode. In this manner, digitized data can be displayed on the electrophoretic display.

Besides the triode-type display, the applicant's herein have proposed a variety of EPID structures for utilizing the electrophoretic effect. For example, an alternative EPID construction is described in Application No. 07/345,825, now U.S. Patent No. 5,053,763, entitled **DUAL ANODE FLAT PANEL ELECTROPHORETIC DISPLAY APPARATUS**, which relates to an electrophoretic display in which the cathode/grid matrix as found in triode-type displays is overlayed by a plurality of independent, separately addressable "local" anode lines. The local anode lines are deposited upon and aligned with the grid lines and are insulated therefrom by interstitial lines of photoresist. The local anode lines are in addition to the "remote" anode, which is the layer deposited upon the anode faceplate or cap as in triode displays. The dual anode structure aforesaid provides enhanced operation by eliminating unwanted variations in display brightness between frames, increasing the speed of the display and decreasing the anode voltage required during Write and Hold cycles, all as explained therein.

In general, it can be noted that a variety of EPID configurations have been proposed by the prior art. It has, however, been a problem in regard to such displays to provide grey scale capability. Grey scale capability is a well known term of art and has been utilized for example in regard to the description of television receivers and various other types of data presentations

such as in facsimile and so on. In U.S. Pat. No. 4,833,464, entitled **ELECTROPHORETIC INFORMATION DISPLAY (EPID) APPARATUS EMPLOYING GREY SCALE CAPABILITY**, there is disclosed an EPID which utilizes a timing generator to produce a series of divided clock signals each having a selected duration of time corresponding to a desired grey scale level. In a first sequence, all dark pixels associated with the entire display are written into at the same time by addressing the X Y grid matrix with a first set of voltages. During subsequent sequences, incrementally shorter voltage applications are used to write increasingly lighter grey pixels associated with the display. The display disclosed therein, while representing an advance over prior art displays which lack grey scale capability, is fairly complex as it requires special timing circuitry.

It is therefore an object of the present invention to provide an electrophoretic information display apparatus which provides grey scale capability, which is of reduced complexity, and which is reliable to operate.

DISCLOSURE OF THE INVENTION

An apparatus for operating an electrophoretic information display with grey scale capability has a plurality of pixel areas each accessible by an X-Y addressing format and each indicative of a given display content at that associated display area. The display comprises means for sequentially applying an electric field across selected pixel areas during a series of equal time intervals, each interval being less than the time necessary to completely remove pigment particles associated with the selected pixel areas therefrom. In this manner, incrementally darker pixels are provided after each successive time interval with the darkest pixels being obtained when all of the pigment particles are removed from corresponding intersections. Thus, a grey scale image is

obtained by re-applying the electric field only to pixel areas which are not of the desired shade after a previous interval.

A method of providing grey scale capability for an electrophoretic information display comprises the steps of applying an electrical field across selected intersections for a fixed interval of time less than that required to completely remove the particles therefrom, thereby causing an image having pixels of a first shade to be formed thereon and applying in a second applying step an electrical field across at least some of said selected intersections for said fixed interval, thereby causing an image having pixels of a second shade darker than said first shade to be formed thereon.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a rear perspective view of an electrophoretic display panel employed with the present invention; and

FIG. 2 is a detailed block diagram depicting an apparatus employed with an electrophoretic display and capable of grey scale operation.

BEST MODE FOR CARRYING OUT THE INVENTION

With reference now to FIG. 1, there is shown the rear side of an electrophoretic display panel 10 as exemplified by U.S. Patent No. 4,742,345 to DiSanto et al., this patent being incorporated herein by reference for showing the general construction and components of an electrophoretic display panel. The panel 10 includes a faceplate typically formed from glass which serves as a substrate upon which is deposited a plurality of independent, electrically conductive cathode members 14 (horizontal rows) using conventional deposition and etching techniques. It is preferred that the cathode members 14 be composed of Indium Tin Oxide (ITO) as set forth in U.S. Patent No.

4,742,345. A plurality of independent grid conductor members 16 are superposed in the horizontal over the cathode members 14 and are insulated therefrom by an interstitial photoresist layer (not shown). The grid members 16 may be formed by coating the photoresist layer with a metal, such as nickel, using sputtering techniques or the like and then selectively masking and etching to yield the intersecting but insulated configuration shown in FIG. 1. Each cathode and grid member 14, 16 terminates at one end of a contact pad 18 or is otherwise adapted to permit connection to display driver circuitry, which circuitry will be described later. An anode cap 20 is sealably affixed to the faceplate 12 and over the cathode and grid members 14 and 16 to form an envelope for containing the dielectric fluid/pigment particle suspension. The anode cap 20 is formed from an insulating material, such as glass, and has an inner surface coating of conductor material to form the anode. Thus by applying voltages to the cathode and grid members 14 and 16 and the anode 20, suspended pigment particles in the dielectric fluid can be made to accumulate near, or disperse from, the intersections of selected cathode and grid members 14 and 16 to translate these voltages into a visible display.

The discrete cathode and grid members 14 and 16 of the electrophoretic display 10 can assume a variety of voltages during operation for controlling the display operations or erase, hold and write at the numerous points of intersection defining a cathode/grid matrix. A workable panel would have a large number of intersections, e.g., 2,200 X 1,700 or a total of 3,740,000 separately addressable intersection points. For ease of illustration, however, a small set of intersections are shown in FIG. 1 and only a single intersection is depicted in the remaining figures. The dimensions of the respective elements have also been greatly enlarged for illustration and are not necessarily in proportion to an actual operational device. Representative illustrations of

electrophoretic displays, their components and electrical circuitry can be seen by referring to U.S. Patent Nos. 4,742,345 and 4,772,820, each being awarded to the inventors herein and which are incorporated by reference herein.

As one can readily ascertain upon reference to the previously cited patents, the pigment at the intersections of selected rows and columns is forced out of wells associated therewith (not shown) by selectively applying voltages to the rows and columns, thereby exposing the dye solution and making such intersections dark. The removal of the pigment from the wells is not instantaneous but requires a period of time, which depends upon the dimensions of the display, the applied voltages, and the properties of the suspension. Applying a potential for too short a period of time to a grid and cathode line intersection results in incomplete removal of pigment from the well at that intersection. Accordingly, a pixel intensity which is less than full black may be obtained by utilizing a scan time which is less than the scan time required to completely remove the pigment from the wells. This essentially is the basis of the present application and such techniques for accomplishing this will be further described.

Referring to FIG. 2, there is shown a top view of a typical X-Y matrix consisting of cathode lines which are arranged in the horizontal plane and grid lines which are perpendicular to the cathode lines and insulated therefrom. Thus, there are shown in FIG. 2 four cathode lines designated 22, 24, 26, and N. It is, of course, understood that the number of cathode lines in the Y direction may consist of hundreds of thousands, depending upon the size of the display. As indicated, insulated from the cathode lines and perpendicular thereto, there are also shown four grid lines, 28, 30, 32, and X. It should also be understood that there can be many more grid lines associated with a typical display..